AD NUMBER
ADB274869
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution: Further dissemination only as directed by Office of Scientific Research and Development, Washington, DC 20301, DEC 1945, or higher DoD authority.**
AUTHORITY
OTS index dtd Jun 1947

12350

COPY NO. 73 [redacted]

[redacted]

OSRD 5849
DECEMBER 1945

OSRD 5849 c.2

OSRD 5849 c.2

UNCLASSIFIED

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

National Defense Research Committee

Division 3 Section ~~H~~

Classification cancelled ~~or changed to:~~
OSRD List # 31
Initials of Officer making the change:
DAB

X-RAY PHOTOGRAPHY OF BURNING ROCKET PROPELLANTS

DISTRIBUTION STATEMENT F:
Further dissemination only as directed by OSD Washington, DC Dec 1945 (20301)
or higher DoD authority.

by

W. P. Spaulding, R. S. Craig, and S. Golden

[redacted]

FINAL REPORT

Series J Number 5

20020104 089

from

ALLEGANY BALLISTICS LABORATORY

Operated by The George Washington University under Contract OEMsr-273

~~CONFIDENTIAL~~

UNCLASSIFIED

[redacted]

UNCLASSIFIED

OSRD 5849
December 1945

X-RAY PHOTOGRAPHY OF BURNING ROCKET PROPELLANTS

Final Report — Series J — Number 5

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C., 50; 31 and 32, as amended. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

Submitted by:

W. P. Spaulding,
R. S. Craig,
and S. Golden

Approved by:

R. E. Gibson
Director of Research
Allegany Ballistics Laboratory

C. N. Hickman

C.N. Hickman, Chief
Section H, Division 3, NDRC

Frederick L. Hovde

Frederick L. Hovde, Chief
Division 3, NDRC

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

Preface

This report concerns the application of X-ray photography to the study of certain ballistic problems in the T59 high-velocity rocket grenade and the 115-mm·aircraft rocket. The report is intended to suggest to rocket experimenters the potentialities of X-ray techniques, as well as to review the significant results obtained in X-ray studies of these specific weapons. Memoranda relating to this project will be found in the Allegany Ballistics Laboratory files under Projects W-60.1 and W-80.

The experimental work, supervised by Major J. C. Clark, was carried out at the Aberdeen Proving Ground (using the facilities of the Army Ordnance Department). Authorization for X-ray studies of the two weapons to be undertaken at Aberdeen was granted by letter from the Office of the Chief of Ordnance, following a request from R. E. Gibson, Director of Research at the Allegany Ballistics Laboratory. The principal expenses incident to the work were borne by the Army Ordnance Department.

X-ray studies of the T59 high-velocity rocket grenade were initiated on August 9, 1944, and the experiments were concluded on November 8, 1944. Similar investigations of the 115-mm rocket project were initiated on July 12, 1945, and the concluding experiments were performed on September 14, 1945.

December 1945

Acknowledgments

The authors wish to express their appreciation to the Army Ordnance Department, and in particular to Major J. C. Clark, for making available the Aberdeen radiographic equipment and for carrying out the experimental work. Much credit is due J.R. Morgan of the Allegany Ballistics Laboratory, who first suggested the use of X-ray techniques and who devoted much thought to planning the original program.

The Allegany Ballistics Laboratory editorial staff edited this report. The staff of the Technical Reports Section, Office of the Chairman, NDRC, did the final editing and the preparation for publication.

UNCLASSIFIED

[redacted]

[redacted]

UNCLASSIFIED

TABLE OF CONTENTS

List of Figures

UNCLASSIFIED

[redacted]

X-RAY PHOTOGRAPHY OF BURNING ROCKET PROPELLANTS

Abstract

Recent developments have made it possible to take high-speed X-ray photographs of rockets in action which reveal the burning propellant and the behavior of the internal components. The method presents unique possibilities for the investigation of certain rocket problems. Applications of X-ray photography have been made in a study of propellant loss in the T59 high velocity rocket grenade and in the 115-mm aircraft rocket.

1. Introduction and recommendations

During the course of rocket developmental work, it is frequently necessary to investigate the causes of anomalous behavior observed in static and flight firings. With the equipment ordinarily used in rocket research, only indirect evidence of the cause of erratic performance is obtained. For example, high pressures in static firings may be a result of failure of the trap or of the propellant, or again it may be normal behavior. In flight firings, low velocities or abrupt changes in velocity may indicate some mechanical failure. The advantage of direct observation of the conditions within the rocket motor is obvious because of the ease with which the difficulty, if any, may be ascertained. Thus corrective measures may be quickly applied.

Recently it has been found possible to draw currents of several thousand amperes for very short time intervals from cold metals by field emission in a vacuum [1] */. X-rays are produced by this process that are of sufficient intensity and of short enough duration to yield clear radiographs of a fast-moving, low-density object, even though it is shielded by a high-density object. This fact suggested the possibility of taking X-ray photographs of rockets that would reveal their internal structure during the burning process.

Using the proper experimental technique it should be possible to observe the following:

(1) The action of the igniter.

(2) The behavior of the propellant; for example, the behavior of restricted-coated propellant grains under drag and pressure forces.

(3) The adequacy of internal mechanical assemblies such as traps.

(4) The nature of rocket chamber failure.

(5) The flow properties of propellant gases, particularly with reference to erosive action upon metal parts and propellant.

(6) The action of the trap and propellant under acceleration forces during flight.

All of the foregoing studies can be made, using suitable techniques, with existing X-ray equipment. By developing proper auxiliary equipment, sequence high-speed radiographs can be obtained making even wider applications possible. Through the use of rocket chambers constructed of metals of low atomic weight — such as beryllium, magnesium, and aluminum,

---

*/ Numbers in square brackets refer to the Bibliography.

which are low in X-ray absorption — and the incorporation of radiographically opaque particles — such as barium salts — in the propellant, radiographs of greater contrast may be obtained.

It may be mentioned that the equipment usually employed in rocket research can easily be used in conjunction with X-ray apparatus. For instance, PIP records [2] (records of pressure versus $\int$Pdt taken with an electronic apparatus using wire strain gages) have been made to provide data for correlating the X-rayed event with the behavior of the propellant charge at the instant of exposure. Electronic pressure-time apparatus has also been used. There should be no difficulty in obtaining the velocity and acceleration of the rocket at the moment of X-ray exposure.

2. Description of the Aberdeen flash radiographic apparatus [3]

The flash radiographic apparatus (Fig. 1), used for the work described in the following, is portable and may be taken by truck to the field location where the tests are to be made. The apparatus consists of three main parts: (i) an X-ray tube that has an auxiliary focusing electrode located near the cathode, connected through a high resistance to the anode to initiate the discharge; (ii) a surge generator; and (iii) an interval timer which is essentially a time-delay circuit producing a pulse that causes the surge generator to function at a predetermined time interval after a signal is put into the timer. The duration of the X-ray discharge on the Aberdeen equipment has been determined from radiographs of high-explosive phenomena to be between 1 and 3 μsec. This interval is short enough to "stop" the action of burning in a rocket.

3. Applications

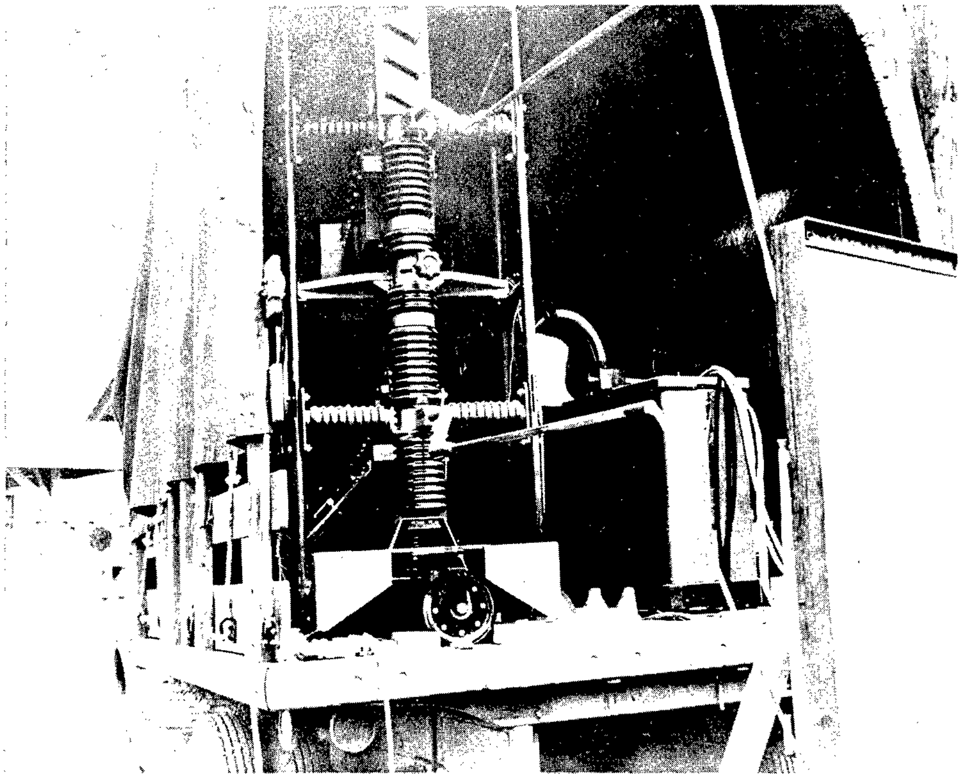
(a) The T59 high-velocity rocket grenade. -- The first application of X-ray technique to the study of the propellant burning process in a rocket was made using the T59 high-velocity rocket grenade (Fig. 2). A series of static tests, directed to providing data on propellant loss at low temperatures, was outlined.

A preliminary radiogram was made with the Aberdeen equipment of a loaded T59 HVRG to determine the ability of the equipment to "see" the propellant disks within the steel rocket chamber. The results were distinctly promising, the propellant being visible in great detail. The apparatus was then set up to take radiograms of the rocket during burning.

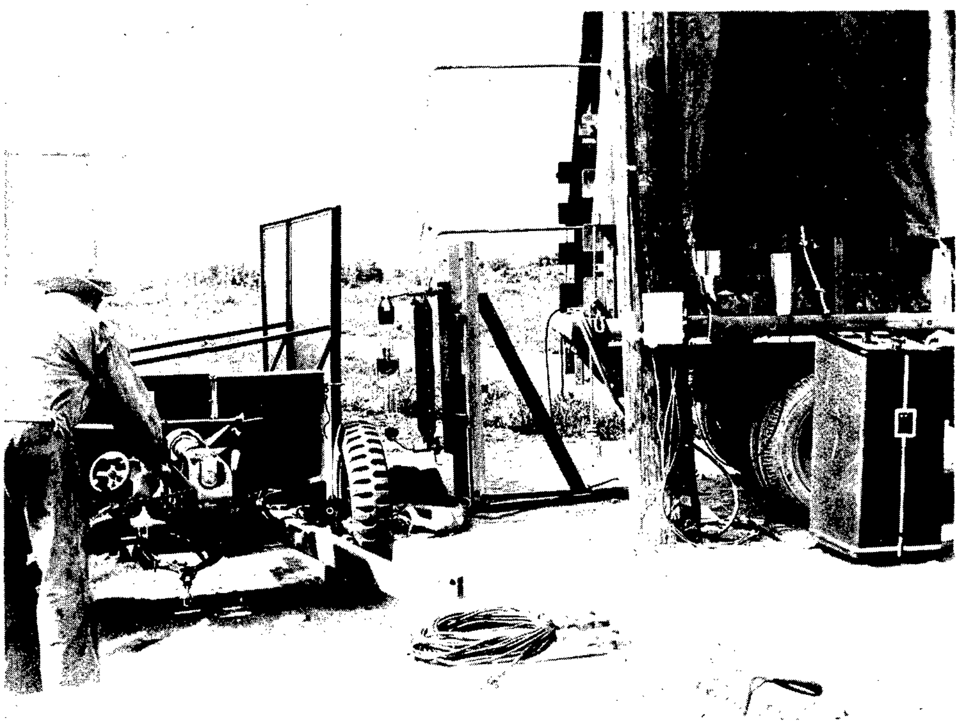
The experimental setup is shown in Fig. 3. The X-ray tube was placed 6.5 ft from the rocket motor. At this distance the X-ray beam divergence is quite small and the effect of the focal spot is thus minimized. For distances greater than 6.5 ft the film contrast was found to be diminished. The film cassette was placed 1.5 in. from the axis of the rocket to insure good definition. Eastman type F films, with Patterson No. 245 intensifying screens, were used.

In conjunction with the X-ray equipment, the PIP apparatus was used to record the ballistic behavior up to the moment of operation of the X-ray tube. The firing of the tube caused the electron beam of the PIP oscilloscope to be thrown off the screen momentarily. This served to fix the radiographed event with respect to the burning time and amount of propellant burned.

In order to obtain the radiograph at some selected time during the burning process a mechanical trigger unit was used. This unit operated by breaking or making a circuit by means of the



(a) HIGH-SPEED X-RAY APPARATUS ON TRUCK FOR TRANSPORTING TO FIELD SETUP



(b) ARRANGEMENT OF ULTRA-HIGH-SPEED X-RAY APPARATUS ABOUT 37-MM GUN

FIG. 1. THE ABERDEEN FLASH RADIOGRAPHIC APPARATUS.

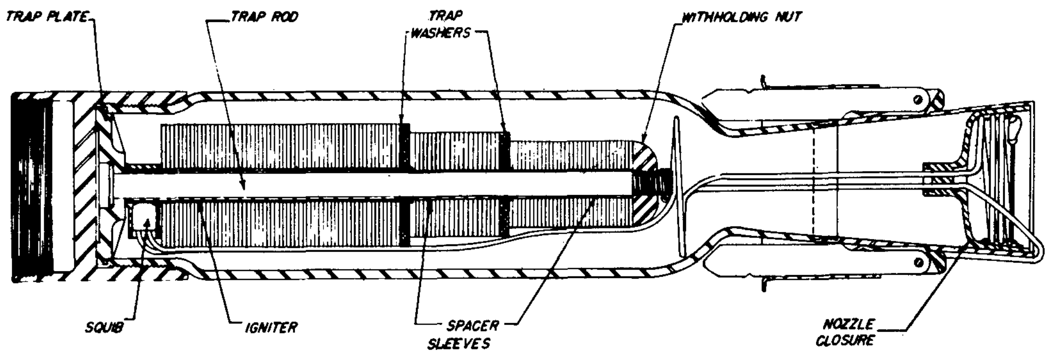


FIG. 2. THE T59 HIGH-VELOCITY ROCKET GRENADE.

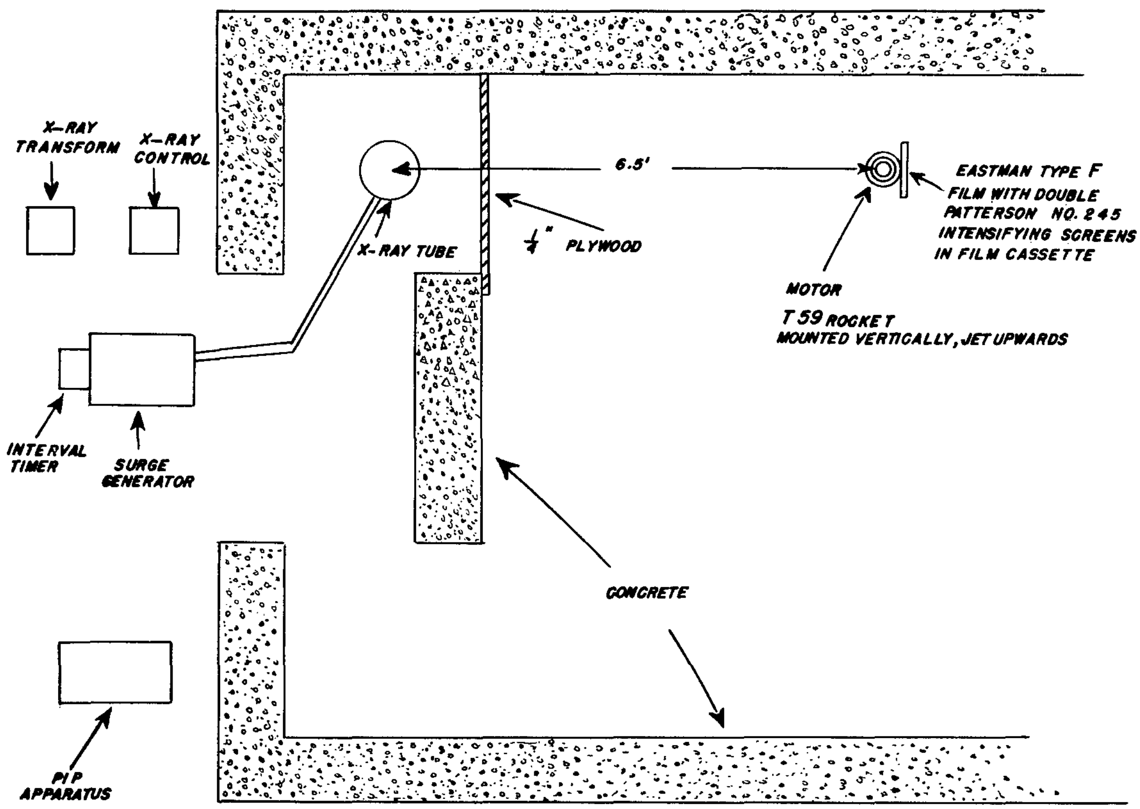


FIG. 3. SETUP TO OBTAIN RADIOGRAPHS OF PROPELLANT BURNING IN T59 ROCKET.

action of the jet. This circuit was connected to the interval timer so that the X-ray tube could be fired at some definite time after jet action began. Because the instant at which jet action began varied from round to round this trigger unit was discarded. In later tests an electronic trigger circuit was connected to the PIP apparatus that caused the X-ray tube to fire when a predetermined pressure had been reached in the rocket.

The T59 charge and trap arrangement can be seen in Fig. 2. The charge consists of three stacks of propellant disks of different outside diameters fitted over a centrally located trap rod. The individual groups are separated by means of metal trap washers of the same diameter as the larger section. The metal washers are fixed relative to the trap rod.

As a result of the tests, several important features of propellant burning in the T59 were revealed. In particular, direct evidence was obtained that loss of propellant was due to a mechanical failure of the propellant disks. Some interesting aspects of the photographs (Fig. 4) are the following.

(1) The film from Round 24 [Fig. 4(a)] shows that propellant breakup can occur when as little as 0.8 percent of the propellant is burned. This may be a result of the action of the igniter, which is in the form of a coated metal tube slipped over the trap rod and situated within the largest-charge section (Fig.2).

(2) The film from Round 13 [Fig. 4(b)] shows that the propellant disks adjacent to the trap washers are lost preferentially to disks in other positions. This was also shown by the film from Round 11, not reproduced here.

(3) The record of Round 20 [Fig. 4(c)] was taken after the maximum pressure had been reached and passed. Propellant is still in evidence.

(4) Round 23 [Fig. 4(d)] is a control showing the configuration of the charge before ignition.

Application of these results to the problem of propellant loss in T59 rocket is discussed in another report [4].

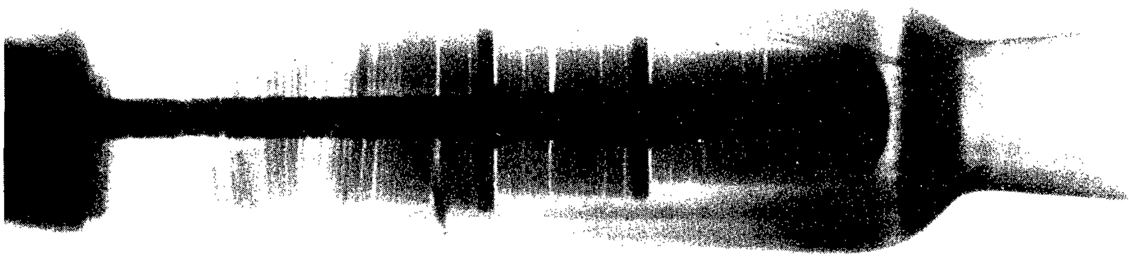
(b) The 115-mm rocket.--The problem of partial propellant failure in the neighborhood of 140°F in the 115-mm rocket has been of interest both from the standpoint of increasing the useful temperature range of the weapon and as a fundamental problem, the solution of which would give insight into similar problems in other weapons. Several modes of attack have been employed. The possibility of the bursting of the grains by excessive internal pressure in the perforation was investigated by theoretical calculations of pressure differences [5], and certain experiments designed to measure the same quantity directly were also performed. The possibility of the mechanical failure of the powder by buckling under the drag forces was investigated in an extensive series of tests on the mechanical strength of propellants [6]. Various traps were designed and tested with a view to decreasing the powder loss by improving the grain support and the venting of the perforation at the rear end. None of these methods of attack, however, was completely successful in determining the mechanism and reasons for failure.

It was believed that more direct evidence might be obtained by X-ray photographs. It might, by this means, be possible directly to observe:

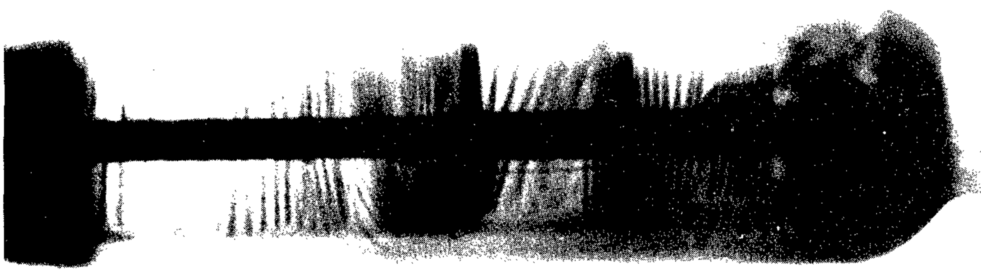
(1) The point of initial failure of the powder.

(2) Possible bending or twisting of the trap and its effect on the propellant.

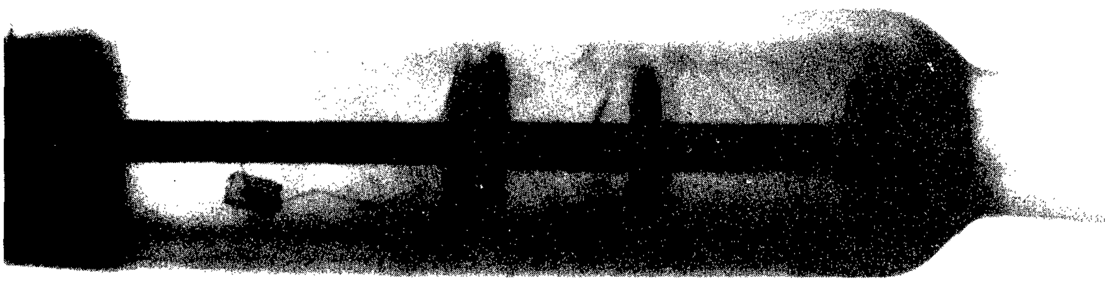
(3) The appearance of the grains, and possibly an indication of the mechanism of failure;



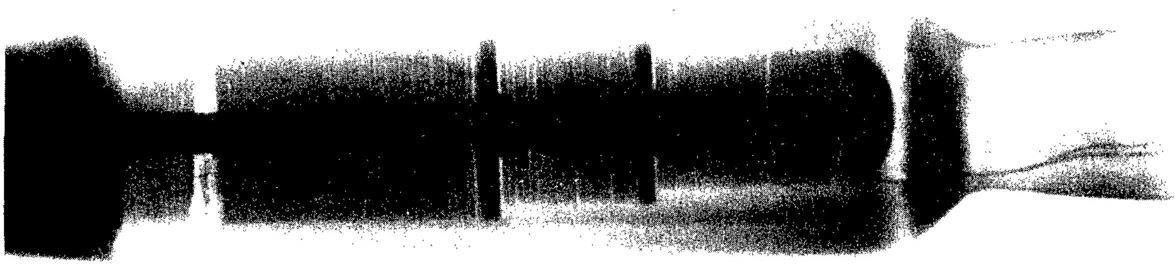
(a) ROUND 24



(b) ROUND 13



(c) ROUND 20

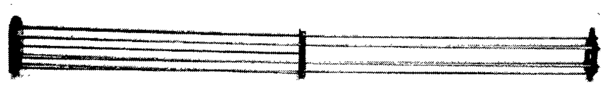


(d) ROUND 23

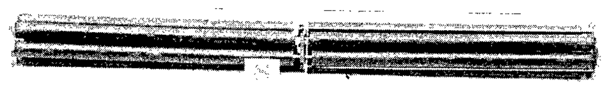
FIG. 4. X-RAY PHOTOGRAPHS OF THE T59 ROCKET.

for example, buckling failure, a ripping or tearing action, or perhaps failure of the grain by bursting under the excessive pressure in the perforation.

It was recognized at the outset that the problem of obtaining high contrast was complicated by the extra thickness of rocket wall compared with that of the T59. Also, the detail of the individual powder grains would be obscured by the overlapping of the grains in their normal position on the trap. The trap and the normal arrangement of the charge are shown in Fig. 5.



(a) TRAP (2010C1) FOR THE 115-MM ROCKET



(b) TRAP (2010C1) AND CHARGE FOR THE 115-MM ROCKET

FIG. 5. TRAP AND PROPELLANT CHARGE FOR THE 115-MM ROCKET.

The rockets were loaded with charges consisting of 20-in. lengths of T2 powder (Hercules Powder Company, Radford Ordnance Works Pilot Lot 672). The charges differed from the standard loading in that the grains were not drilled with four radial holes through one web. These undrilled charges were used to induce powder failure at lower temperatures — such charges had given consistent failure at 130°F in static firings. The motors were mounted in a vertical position 50 in. from the X-ray source. The photographic plates (17 in. by 4 in.) were mounted on a wooden frame about 1 cm from the chamber wall. The time of the X-ray flash was controlled by a thyratron delay circuit actuated by the breaking of a wire above the nozzle. Pressure-time records of each shot were taken with electronic strain-gage equipment. The time at which the X-ray flash occurred was clearly given on each record by a sharp deflection in the trace produced by "pick-up" from the circuit supplying the X-ray tube.

The typical radiographs shown in Fig. 6 are described in sequence in the following.

Figure 6(a) is a radiograph of Round 2 taken 23 msec after the beginning of the rise of pressure in the motor. The maximum pressure of this round, which occurred 51 msec after the beginning of pressure rise, was 5600 lb/in.^{2}, indicating that partial propellant failure took place. The X-ray beam was centered opposite the center trap plate. The film shows the rear end of the front tier of powder grains and to the extreme right, the front end of the rear tier of powder grains. From the distance between the trap plate and the rear tier, it appears that the grains are under compression. No breakup was observed in the front tier of powder in any of the rounds.

Figure 6(b), a radiograph of Round 4, was taken approximately 30 msec after the beginning of the pressure rise and was practically coincident with the maximum pressure. The X-ray beam was centered about 4 in. forward of the rear trap plate. The trap failure seen here is probably the result of neglecting to wrap a wire around the trap rods at the head end during loading. It is possible for rods not thus fastened to become loose during shipment of the rounds. Broken grains can be seen in the space behind the rear plate, having apparently been ripped off the trap rods.

Figure 6(c), Round 5, shows the rear tier 31 msec after the beginning of pressure rise. The maximum pressure occurred 20 msec later. No powder fragments can be seen here, thougn breakup occurred later as was evident from the fragments blown out through the nozzle. The bending of the trap rods is probably caused by the bowing of the compressed powder.

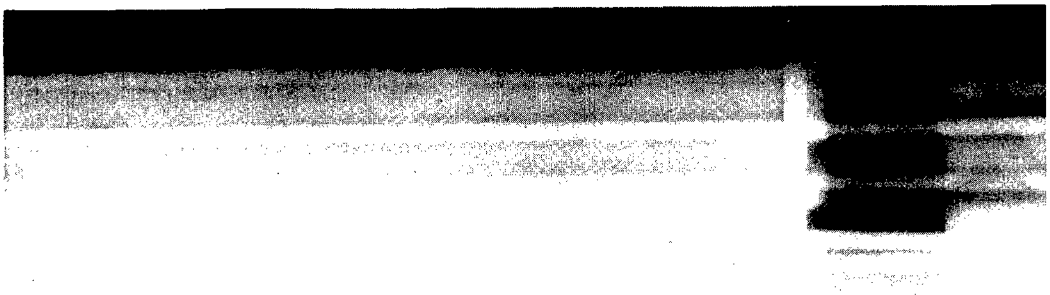
Figure 6(d), Round 6, shows the rear tier 73 msec after the beginning of pressure rise and 9 msec after the maximum pressure. Here much of the rear tier of powder has been lost. The distended appearance of one of the fragments suggests that the grains may have been ruptured by excessive internal pressure during the transient period, though the mechanical ripping or stripping of the grains from the trap rods might give the same picture.

Application of these results to the problem of propellant loss in the 115-mm rocket is discussed in another report [7].

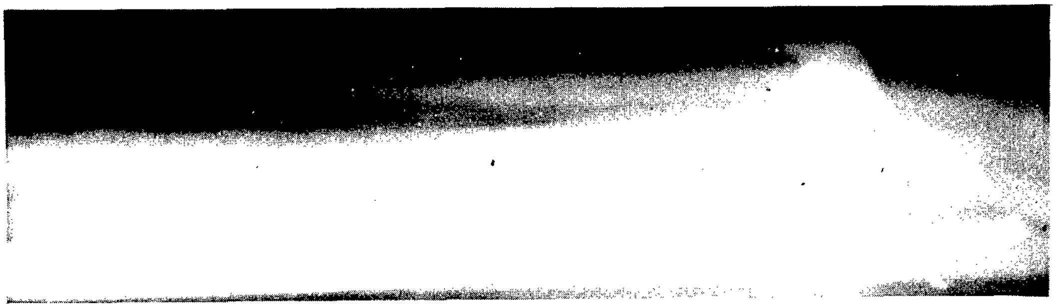
4. Conclusions

X-ray photographs of rockets have been obtained that revealed the internal structure during the burning of the propellant. The pictures that were obtained have permitted the direct observation of the conditions within the rocket during the burning process. These pictures have thrown light upon the problems of propellant failure in the T59 high-velocity rocket grenade and the 115-mm aircraft rocket.

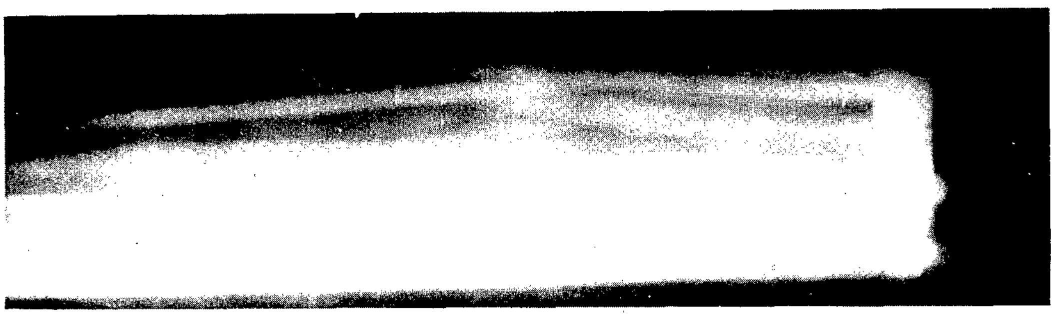
Although the application of X-rays to rockets has not been applied extensively, the successes that have been obtained suggest strongly the further application of radiography to experimental rocket research.



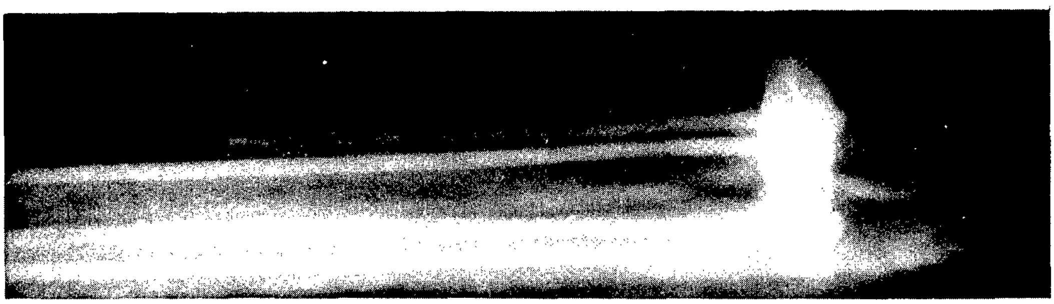
(a) ROUND 2, 23 MSEC AFTER INITIAL PRESSURE RISE, FRONT AND REAR TIER



(b) ROUND 4, 30 MSEC AFTER INITIAL PRESSURE RISE, REAR TIER



(c) ROUND 5, 31 MSEC AFTER INITIAL PRESSURE RISE, REAR TIER



(d) ROUND 6, 73 MSEC AFTER INITIAL PRESSURE RISE, REAR TIER

FIG. 6. X-RAY PHOTOGRAPHS OF THE 115-mm ROCKET.

BIBLIOGRAPHY

[1] C. N. Slack and L. F. Ehrke, Field emission X-ray tube, J. Appl. Phys., Vol. 12, No. 2, pp. 165-168 (Feb. 1941).

[2] S. Golden and C. M. Lathrop, Apparatus for the recording of pressure versus $\int Pdt$, ABL Final Report J-2 (OSRD-5859).

[3] Capt. J. C. Clark, Flash radiograms of burning rocket propellants, Army Ordnance Department, Ballistic Research Laboratory Memorandum Report 323.

[4] S. Golden, W. P. Spaulding, and L. E. Morey, T59 high-velocity rocket grenade (Super Bazooka), ABL Final Report W-6 (OSRD-5779).

[5] M. Dresner and F. T. McClure, Theoretical considerations of gas flow in rocket motors, ABL Final Report B-1.1 (OSRD-5874).

[6] H. Higbie, Physical properties of propellants, ABL Final Report P-8 (OSRD-5845).

[7] J. Beek, R. L. Arnett, G. W. Engstrom, and M. Goldman, Development of propellant charge for 115-mm aircraft rocket, ABL Final Report W-8.1 (OSRD-5784).

DISTRIBUTION LIST

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT (1-21)

1. Office of the Executive Secretary, OSRD
2. Chairman, NDRC
3. Division 3, NDRC
4. Section H, Division 3, NDRC
5-21. Liaison Office, OSRD

CONTRACTOR (22)

22. The George Washington University

WAR DEPARTMENT (23-77)

23-32. Army Air Forces Liaison Officer for NDRC

33-44. Army Ground Forces Liaison Officer for NDRC, for
Col. B. A. Day

45-50. War Department Liaison Officer for NDRC, for
- 45-47. War Department Liaison Officer for NDRC
- 48. Research and Development Division
- 49. New Developments Division, War Department Special Staff
- 50. Dr. E. L. Bowles, Office of the Secretary of War

51-53. Quartermaster Corps Liaison Officer for NDRC, for
Capt. R. R. Walton

54-59. Chemical Warfare Service Liaison Officer for NDRC, for
Offense Matériel Branch, Gravelly Point, Va.

60-69. Corps of Engineers Liaison Officer for NDRC, for
Maj. M. D. Kirkpatrick, Fortification Branch

70-77. Ordnance Department Liaison Officer for NDRC, for
- 70. Rocket Development Division
- 71. SPOTX-AR
- 72. Technical Division, Picatinny Arsenal
- 73-74. Rocket Research Division, SPOTZ-D, Aberdeen Proving Ground
- 75. Lt. Col. C. H. Greenall, Frankford Arsenal
- 76-77. Office of the Ordnance Officer, U.S. Military Academy

UN[redacted]FIED

NAVY DEPARTMENT (78-145)

78-116. Office of Research and Inventions, for
- 78-89. Research and Development Division
- 90. Special Devices Division
- 91-92. Engineering Experimental Station, Annapolis, Md.
- 93-94. Armament Test Unit, Naval Air Station, Patuxent River, Md.
- 95-98. Bureau of Aeronautics Representative, Aerojet Engineering Corporation, Pasadena, Calif.
- 99-100. Naval Ordnance Laboratory
- 101-106. Naval Ordnance Test Station, Inyokern, Calif.
- 107-108. Naval Powder Factory, Indian Head, Md.
- 109-110. Naval Proving Ground, Dahlgren, Va.
- 111-112. Head of Department of Ordnance and Gunnery, U.S. Naval Academy
- 113-114. David W. Taylor Model Basin
- 115-116. COMINCH, Operational Development Force, c/o Fleet Post Office, New York

117-119. Office of the Commander-in-Chief, U.S. Fleet, for
- 117-118. Readiness Division, New Weapons Research and Development Section (F45)
- 119. Operations Research Group

120-125. Office of the Chief of Naval Operations, for
- 120-121. Deputy Chief of Naval Operations
- 122. Aviation Military Characteristics (Op-03-5)
- 123-125. Progress Section (Op-050G)

126-131. Bureau of Aeronautics, Engineering Division, for
- 126. Deputy Director, Experiments and Developments
- 127-128. Armament Branch
- 129-130. Ship's Installation Branch
- 131. Power Plants Branch

132-141. Bureau of Ordnance, Research and Development Division, for
- 132-133. Assistant for Rockets and Jet Propulsion (Red)
- 134-139. Ammunition and Explosives (Re2)
- 140-141. Armor and Projectiles (Re3)

142-143. Bureau of Ships, Research and Standards Section (330)

144-145. U.S. Naval Research Laboratory

DIVISION 3, NDRC (146-190)

UNCLASSIFIED

[redacted]